ISSN: 2754-4753

Journal of Physics & Optics Sciences

SCIENTIFIC Research and Community

Review Article

Open Access

Relativistic Modeling of Charged Anisotropic Stars in a Buchdahl Spacetime

Manuel Malaver[1]* and Rajan Iyer[2]

[1]Department of Basic Sciences, Maritime University of the Caribbean, Venezuela

[2]Department of Physical Mathematics Sciences Engineering, Engineering International Operational Teknet Earth Global, United States of America

ABSTRACT

In this paper, we studied the behavior of relativistic objects with charged anisotropic matter distribution with a linear equation of state considering a metric potential proposed for Buchdahl (1959). The new solutions to the Einstein-Maxwell system of equations are found in term of elementary functions. A physical analysis of electromagnetic field indicates that is regular in the origin and well behaved. The new obtained models satisfy all physical requirements of a physically reasonable stellar object. The models are consistent with the upper limit on the mass of compact stars for PSR J1823-3021G, PSR J1748-2446an and PSR J1518+4904.

***Corresponding author**

Manuel Malaver, Department of Basic Sciences, Maritime University of the Caribbean, Venezuela.

Received: August 29, 2024; **Accepted:** September 12, 2024; **Published:** October 07, 2024

Keywords: Relativistic Objects, Anisotropic Matter, Einstein-Maxwell System, Metric Potential, Compact Star

Introduction

Research on compact objects and strange stars within the framework of the general theory of relativity is a central issue of great importance in theoretical astrophysics in the last decades [1,2]. The obtained models in general relativity have been used to describe fluid spheres with strong gravitational fields as is the case of white dwarfs and neutron stars [3-5].

In theoretical works of realistic stellar models, is important include the pressure anisotropy [6-18]. Bowers and Liang extensively discuss the effect of pressure anisotropy in general relativity [6] The existence of anisotropy within a star can be explained by the presence of a solid core, phase transitions, a type III super fluid, a pion condensation or another physical phenomena as the presence of an electrical field [18,19]. The physics of ultrahigh densities is not well understood and many of the strange stars studies have been performed within the framework of the MIT-Bag model [20]. In this model, the strange matter equation of state has a simple linear form given by where is the energy $p=\frac{1}{3}(\rho-4B)$ density, p is the isotropic pressure and B is the bag constant. Many researchers have used a great variety of mathematical techniques to try to obtain exact solutions for quark stars within the framework of MIT-Bag model: Komathiraj and Maharaj found two new classes of exact solutions to the Einstein-Maxwell system of equations with a particular form of the gravitational potential and isotropic pressure [20]. Malaver also has obtained some models for quark stars considering a potential gravitational that depends on an adjustable parameter [21,22]. Thirukkanesh and Maharaj studied the behavior of compact relativistic objects with anisotropic pressure in the presence of the electromagnetic field. Maharaj et al. generated new models for quark stars with charged anisotropic matter considering a linear equation of state [23, 24]. Thirukkanesh and Ragel obtained new models for compact stars with quark matter [25]. Sunzu et al. found new classes of solutions with specific forms for the measure of anisotropy [26].

With then use of Einstein´s field equations, important advances has been made to model the interior of a star. In particular, Feroze and Siddiqui and Malaver consider a quadratic equation of state for the matter distribution and specify particular forms for the gravitational potential and electric field intensity [27-30]. Mafa Takisa and Maharaj obtained new exact solutions to the Einstein-Maxwell system of equations with a polytropic equation of state [31]. Thirukkanesh and Ragel have obtained particular models of anisotropic fluids with polytropic equation of state which are consistent with the reported experimental observations [32]. Malaver generated new exact solutions to the Einstein-Maxwell system considering Van der Waals modified equation of state with and without polytropical exponent and Thirukkanesh and Ragel presented a anisotropic strange quark matter model by imposing a linear barotropic equation of state with Tolman IV form for the gravitational potential [33-35]. Mak and Harko found a relativistic model of strange quark star with the suppositions of spherical symmetry and conformal Killing vector [36]. Malaver and Iyer obtained new class of solutions for the Einstein-Maxwell field equations for charged anisotropic matter with a Tolman IV type potential [37].

The aim of this paper is to obtain new exact solutions to the Maxwell-Einstein system for charged anisotropic matter with the barotropic equation of state that presents a linear relation between the energy density and the radial pressure in static spherically symmetric spacetime using the metric potential proposed for Buchdahl to generate some stellar models with anisotropic matter distribution [38]. We obtained some new classes of static spherically symmetrical models. This article is organized as follows, in Section 2, we present Einstein´s field equations of anisotropic fluid distribution. In Section 3, we make a particular choice of gravitational potential Z(x) that allows solving the field equations and we have obtained new models for charged anisotropic matter. In Section. 4, physical requirements for the new models are described. In Section 5, a physical analysis of the new solutions is performed. Finally in Section 6, we conclude.

Einstein Field Equations

We consider a spherically symmetric, static and homogeneous and anisotropic spacetime in Schwarzschild coordinates given by

$$ds^2 = -e^{2\nu(r)}dt^2 + e^{2\lambda(r)}dr^2 + r^2(d\theta^2 + \sin^2\theta d\varphi^2) \tag{1}$$

where $\nu(r)$ and $\lambda(r)$ are two arbitrary functions.

The Einstein field equations for the charged anisotropic matter are given by

$$T_{00} = -\rho - \frac{1}{2}E^2 \tag{2}$$

$$T_{11} = p_r - \frac{1}{2}E^2 \tag{3}$$

$$T_{22} = T_{33} = p_t + \frac{1}{2}E^2 \tag{4}$$

where ρ is the energy density, ρ_r is the radial pressure, E is electric field intensity and p_t is the tangential pressure, respectively. Using the transformations, $x = cr^2$, $Z(x) = e^{-2\lambda(r)}$ and $A^2y^2(x) = e^{2\nu(r)}$ with arbitrary constants A and c>0, suggested by Durgapal and Bannerji [39], the metric (1) take the form

$$ds^2 = -e^{2\nu(r)}dt^2 + e^{2\lambda(r)}dr^2 + r^2(d\theta^2 + \sin^2\theta d\varphi^2) \tag{5}$$

and the Einstein field equations can be written as

$$\frac{1-Z}{x} - 2\dot{Z} = \frac{\rho}{c} + \frac{E^2}{2c} \tag{6}$$

$$4Z\frac{\dot{y}}{y} - \frac{1-Z}{x} = \frac{p_r}{c} - \frac{E^2}{2c} \tag{7}$$

$$4xZ\frac{\ddot{y}}{y} + (4Z + 2x\dot{Z})\frac{\dot{y}}{y} + \dot{Z} = \frac{p_t}{c} + \frac{E^2}{2c} \tag{8}$$

$$p_t = p_r + \Delta \tag{9}$$

$$\frac{\Delta}{c} = 4xZ\frac{\ddot{y}}{y} + \dot{Z}\left(1 + 2x\frac{\dot{y}}{y}\right) + \frac{1-Z}{x} - \frac{E^2}{c} \tag{10}$$

$$\sigma^2 = \frac{4cZ}{x}\left(x\dot{E} + E\right)^2 \tag{11}$$

σ is the charge density and dots denote differentiation with respect to x. With the transformations of [39], the mass within a radius r of the sphere take the form

$$M(x) = \frac{1}{4c^{3/2}}\int_0^x \sqrt{x}\rho(x)dx \tag{12}$$

The interior metric (1) with the charged matter distribution should match the exterior spacetime described by the Reissner-Nordstrom metric

$$ds^2 = -\left(1 - \frac{2M}{r} + \frac{Q^2}{r^2}\right)dt^2 + \left(1 - \frac{2M}{r} + \frac{Q^2}{r^2}\right)dr^2 + r^2(d\theta^2 + \sin^2\theta d\varphi^2) \tag{13}$$

where the total mass and the total charge of the star are denoted by M and q^2, respectively. The junction conditions at the stellar surface are obtained by matching the first and the second fundamental forms for the interior metric (1) and the exterior metric (13).

In this paper, we assume the following lineal equation of state

$$p_r = \frac{1}{3}\rho \tag{14}$$

A New Class of Models

In order to solve the Einstein field equations, we have chosen specific forms for the gravitational potential Z(x) and the electrical field intensity E following Buchdahl [38] and Lighuda et al.[40] we have taken the forms, respectively

$$Z(x) = \frac{K + x}{K(1 + x)} \tag{15}$$

$$\frac{E^2}{2c} = \frac{ax}{1 + ax^2} \tag{16}$$

where K is a parameter related to the geometry of the star and a is a real constant. The metric potential is regular at the origin and well behaved in the interior of the sphere. The electric field is finite at the center of the star and remains continuous in the interior. Substituting (15) and (16) in (6) we obtain

$$\rho = c\left[\frac{(K-1)(1+x) + 2(K-1)}{K(1+x)^2} - \frac{ax}{1+ax^2}\right] \tag{17}$$

we have for the radial pressure

$$P_r = \frac{1}{3}c\left[\frac{(K-1)(1+x) + 2(K-1)}{K(1+x)^2} - \frac{ax}{1+ax^2}\right] \tag{18}$$

Using (17) in (12), the expression of the mass function is

$$M(x) = -\frac{\sqrt{x}}{2\sqrt{c}}\left[\frac{K+x}{K(x+1)}\right] + \frac{\sqrt{2}\left(\frac{1}{a}\right)^{1/4}}{8\sqrt{c}}\left[\begin{array}{l}\arctan\left(\dfrac{\sqrt{2x}}{\left(\frac{1}{a}\right)^{1/4}} + 1\right) + \arctan\left(\dfrac{\sqrt{2x}}{\left(\frac{1}{a}\right)^{1/4}} - 1\right) + \\ \dfrac{1}{2}\ln\left(\dfrac{x + \sqrt{2x}\left(\frac{1}{a}\right)^{1/4} + \sqrt{\frac{1}{a}}}{x - \sqrt{2x}\left(\frac{1}{a}\right)^{1/4} + \sqrt{\frac{1}{a}}}\right)\end{array}\right] \tag{19}$$

With (15) and (16) in eq. (11), the charge density is

$$\sigma^2 = \frac{2ac^2(K+x)\left[2+\sqrt{2}+\left(2-\sqrt{2}\right)ax^2\right]^2}{K(1+x)\left(1+ax^2\right)^3} \tag{20}$$

With (15), (16) and (18), the eq. (7) becomes

$$\frac{4(K+x)\dot{y}}{K(1+x)y} = \frac{K(1+x)-(K+x)}{Kx(1+x)} + \frac{(K-1)(1+x)+2(K-1)}{3cK(1+x)^2} - \frac{ax}{3c\left(1+ax^2\right)} - \frac{ax}{1+ax^2} \tag{21}$$

Integrating (21), we obtain

$$y(x) = c_1(1+x)^{1/6}(K+x)^{A*}\left(1+ax^2\right)^B e^{C\arctan\left(x\sqrt{a}\right)} \tag{22}$$

where for convenience

$$A_* = -\frac{aK^2-2K+3}{6\left(aK^2+1\right)} \tag{23}$$

$$B = -\frac{K(aK+1)}{6\left(aK^2+1\right)} \tag{24}$$

$$C = \frac{\sqrt{a}K(K-1)}{3\left(ak^2+1\right)} \tag{25}$$

The metric functions can be written as

$$e^{2\lambda(r)} = \frac{K(1+x)}{K+x} \tag{26}$$

$$e^{2\nu(r)} = A^2c_1^2(1+x)^{1/3}(K+x)^{2A}\left(1+ax^2\right)^{2B}e^{2C\arctan\left(x\sqrt{a}\right)} \tag{27}$$

The anisotropy factor Δ is given by for

$$\Delta = \frac{4xc(K+x)}{K(1+x)}\left[\begin{array}{l}\frac{A_*^2-A_*}{(K+x)^2}+\frac{A_*}{3(K+x)(1+x)}+\frac{4A_*Bax+2A_*C\sqrt{a}}{(K+x)\left(1+ax^2\right)}-\frac{5}{36(1+x)^2}\\ +\frac{2Bax+C\sqrt{a}}{3(1+x)\left(1+ax^2\right)}+\frac{4\left(B^2-B\right)a^2x^2}{\left(1+ax^2\right)^2}+\frac{2Ba}{1+ax^2}+\frac{2(2B-1)Ca^{3/2}x}{\left(1+ax^2\right)^2}+\frac{C^2a}{\left(1+ax^2\right)^2}\end{array}\right] \tag{28}$$

$$\frac{(1-K)c}{K(1+x)^2}\left[1+2x\left(\frac{A_*}{K+x}+\frac{1}{6(1+x)}+\frac{2Bax+C\sqrt{a}}{1+ax^2}\right)\right]+\frac{c(K-1)}{K(1+x)}-\frac{2acx}{1+ax^2}$$

Conditions of Physical Acceptability

For a model to be physically acceptable, the following conditions should be satisfied [32,41]

1. The metric potentials $e^{2\lambda}$ and $e^{2\nu}$ assume finite values throughout the stellar interior and are singularity-free at the center r=0.
2. The energy density ρ should be positive and a decreasing function inside the star.
3. The radial pressure also should be positive and a decreasing function of radial parameter.
4. The radial pressure and density gradients $dP_r/dr \leq 0$ and $d\rho/dr \leq 0$ for $0 \leq r \leq R$.
5. The anisotropy is zero at the center r=0, i.e. $\Delta(r=0)=0$. Any physically acceptable model must satisfy the causality
6. condition, that is, for the radial sound speed $v_{sr}^2 = \frac{dP_r}{d\rho}$, we should have $0 \leq v_{sr}^2 \leq 1$.
7. The charged interior solution should be matched with the Reissner–Nordström exterior solution, for which the metric is given by the equation (13).

The conditions (2) and (4) imply that the energy density must reach a maximum at the centre and decreasing towards the surface of the sphere.

Physical Analysis the New Models

For the new solutions, metric potentials $e^{2\lambda}$ and $e^{2\nu}$ have finite values and remain positive throughout the stellar interior. At the center $e^{2\lambda(0)}=1$ and $e^{2\nu(0)}=A^2c_1^2K^{2A}e^{2C}$. We show that in $r=0$ $\left(e^{2\lambda(r)}\right)'_{r=0}=\left(e^{2\nu(r)}\right)'_{r=0}=0$

and this make is possible to verify that the gravitational potentials are regular at the center.

The energy density is positive and well behaved between the center and the surface of the star. In the center $\rho(r=0)=\frac{3c(K-1)}{K}$

In the surface of the star $P_r(r=R)=0$ and for the second fundamental form we have

$$\frac{(K-1)\left(1+cR^2\right)+2(K-1)}{K\left(1+cR^2\right)^2}-\frac{acR^2}{1+acR^4}=0 \tag{29}$$

Energy density and radial pressure gradients $\frac{d\rho}{dr}$ and $\frac{dP_r}{dr}$ respectively, are monotonically decreasing functions with the radial coordinate r. For this case we obtain in $0 \leq r \leq R$

$$\frac{d\rho}{dr}=\frac{2(K-1)c^2r}{K\left(1+cr^2\right)^2}-\frac{4\left((K-1)\left(1+cr^2\right)+2K-2\right)c^2r}{K\left(1+cr^2\right)^3}-\frac{2ac^2r}{ac^2r^4+1}+\frac{4a^2c^4r^5}{\left(1+ac^2r^4\right)^2}<0 \tag{30}$$

$$\frac{dP_r}{dr}=\frac{2(K-1)c^2r}{3K\left(1+cr^2\right)^2}-\frac{4\left((K-1)\left(1+cr^2\right)+2K-2\right)c^2r}{3K\left(1+cr^2\right)^3}-\frac{2ac^2r}{3ac^2r^4+1}+\frac{4a^2c^4r^5}{3\left(1+ac^2r^4\right)^2}<0 \tag{31}$$

From the equations (30) and (31) is deduced that the pressure and density should be maximum at the center and monotonically decreasing towards the surface of the star.

On the boundary $r=R$, the solution must match the Reissner–Nordström exterior space–time as

$$ds^2=-\left(1-\frac{2M}{r}+\frac{Q^2}{r^2}\right)dt^2+\left(1-\frac{2M}{r}+\frac{Q^2}{r^2}\right)^{-1}dr^2+r^2\left(d\theta^2+\sin^2 d\varphi^2\right)$$

and therefore, the continuity of e^{ν} and e^{λ} across the boundary $r=R$ is

$$e^{2\nu}=e^{-2\lambda}=1-\frac{2M}{R}+\frac{Q^2}{R^2} \tag{32}$$

Then for the matching conditions, we obtain

$$\frac{2M}{R}=\frac{(K-1)cR^2+2ac^2KR^4+(3K-1)ac^3R^6}{K\left(1+cR^2\right)\left(1+ac^2R^4\right)} \tag{33}$$

Table 1 shows the values of the chosen physical parameters *a*, *K* and the masses of the stellar objects.

Table 1: Parameters K, a and Stellar Masses

K	*a*	*M(MΘ)*
6	0.0002	2.71
8	0.0002	2.87
10	0.0002	2.96

*M*Θ = sun's mass

The figures 1,2,3,4,5,6,7,8 and 9 represent the plots of

$e^{2\lambda}$, $e^{2\nu}$, ρ, P_r, $\frac{d\rho}{dr}$, $\frac{dP_r}{dr}$, M, σ^2 and *Δ* with the radial coordinate.In all the graphs we considered *c*=1.

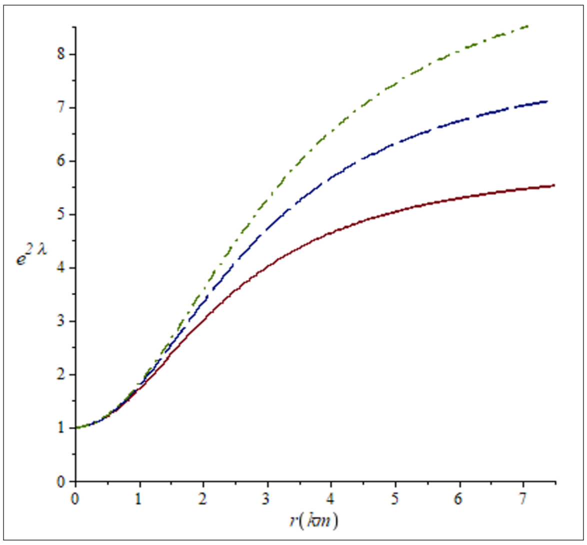

Figure 1: Metric potential $e^{2\lambda}$ against the radial coordinate for *K*=6 (solid line), *K*=8 (long- dash line) and *K*=10 (dash-dot line). For all the cases *a*=0.0002.

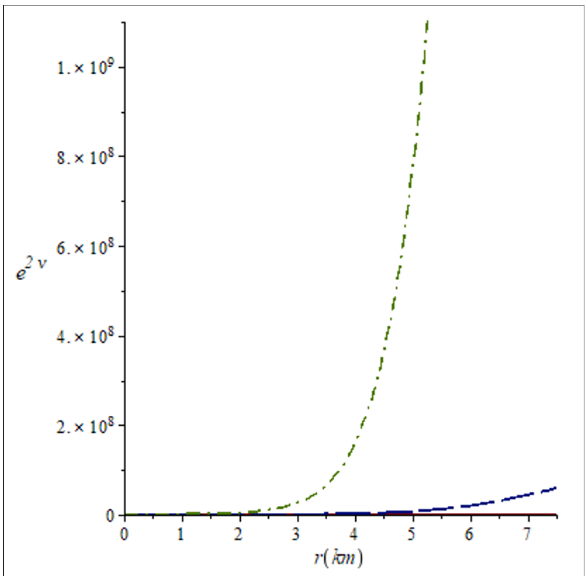

Figure 2: Metric potential against the radial coordinate for *K*=6 (solid line), *K*=8 (long- dash line) and *K*=10 (dash-dot line). For all the cases *a*=0.0002.

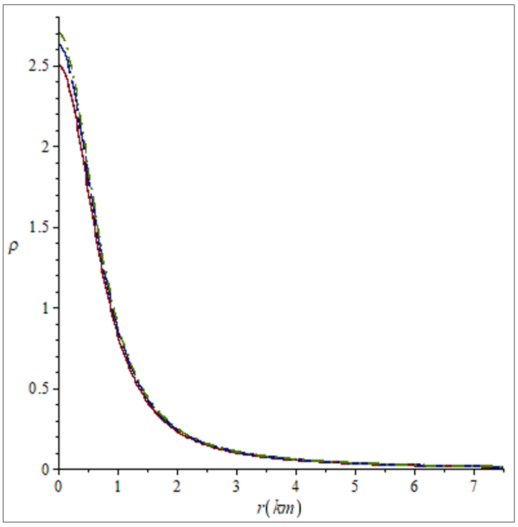

Figure 3: Energy density *ρ* against the radial coordinate for *K*=6 (solid line), *K*=8 (long- dash line) and *K*=10 (dash-dot line). For all the cases *a*=0.0002.

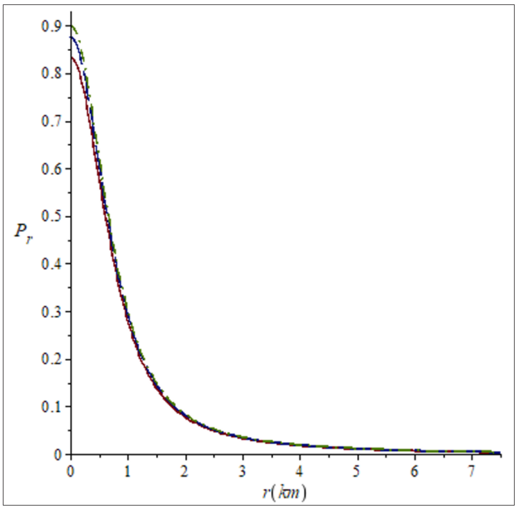

Figure 4: Radial pressure P_r against the radial coordinate for *K*=6 (solid line), *K*=8 (long- dash line) and *K*=10 (dash-dot line). For all the cases *a*=0.0002.

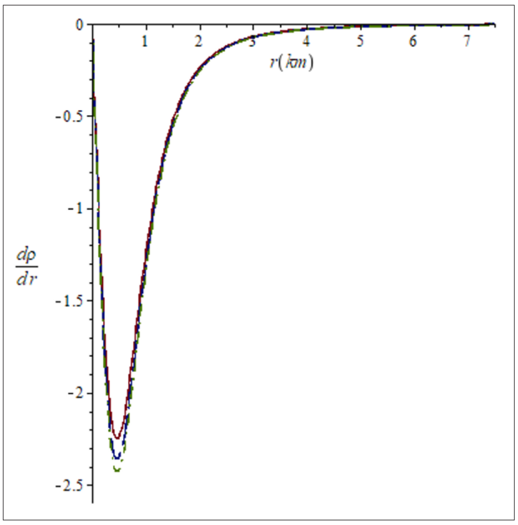

Figure 5: Energy density gradient against the radial coordinate for *K*=6 (solid line), *K*=8 (long- dash line) and *K*=10 (dash-dot line). For all the cases *a*=0.0002.

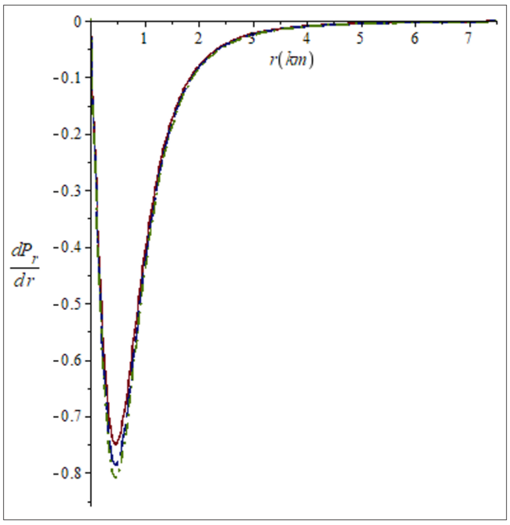

Figure 6: Radial pressure gradient against the radial coordinate for K=6 (solid line), K=8 (long- dash line) and K=10 (dash-dot line). For all the cases a=0.0002.

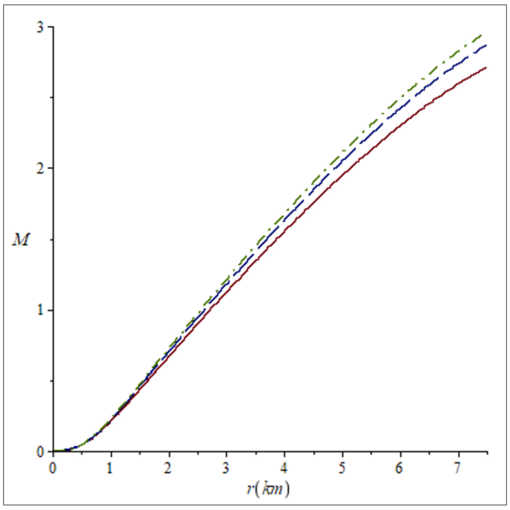

Figure 7: Mass function against the radial coordinate for K=6 (solid line), K=8 (long- dash line) and K=10 (dash-dot line). For all the cases a=0.0002.

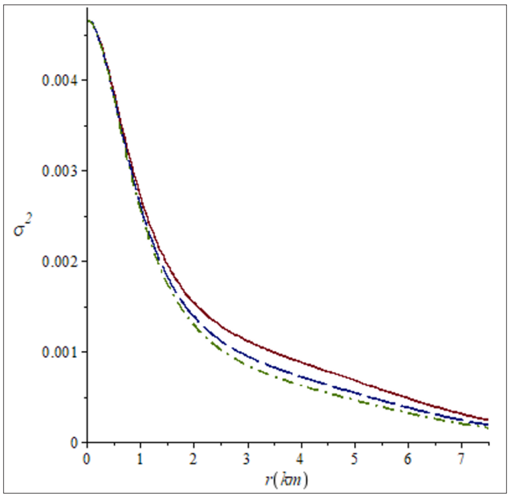

Figure 8: Charge density σ^2 against the radial coordinate for K=6 (solid line), K=8 (long- dash line) and K=10 (dash-dot line). For all the cases a=0.0002.

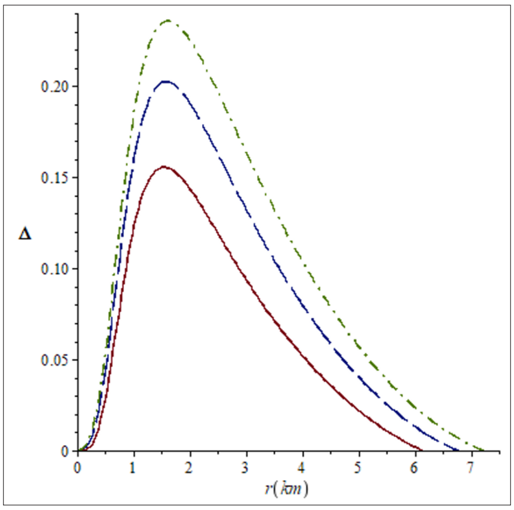

Figure 9: Anisotropy against the radial coordinate for K=6 (solid line), K=8 (long- dash line) and K=10 (dash-dot line). For all the cases a=0.0002.

In Figure 1, for different values of parameter K, the metric potential $e^{2\lambda}$ is a continuously growing function within the star and takes higher values when K is increased. In Figure 2, the metric potential $e^{2\nu}$ also is continuous and has the same behaviour that $e^{2\lambda}$ reaching high values when growing K. The energy density remains positive, continuous and is monotonically decreasing function throughout the stellar interior as noted in the Figure 3 for all values of K considered. The radial pressure is non negative and is a decreasing function with the radial parameter as shown in Figure 4. The radial variation of energy density gradient has been shown in Figure 5, in which it is observed that $\frac{d\rho}{dr} < 0$ in all the cases studied. In Figure 6 is also shown that the profile of $\frac{dP_r}{dr}$ indicates that the radial pressure gradient is negative inside the star. In Figure 7, the mass function is continuous, increasing, takes finite values and well behaved in the stellar interior for different values of K. The charge density is a continuously decreasing function as noted in Figure 8. The anisotropic factor Δ is plotted in Figure 9 and it shows that vanishes at the centre of the star, i.e. $\Delta(r=0)$ =0. We can also note that Δ admits higher values with a growth of K.

We can compare the values calculated for the mass function with observational data of some astrophysical objects such as for PSR J1823-3021G, PSR J1748-2446an and PSR J1518+4904 [42-44]. The values of the stellar masses for these compact stars are tabulated in Table 2.

Table 2: The Approximate Values of the Masses for the Compact Stars

Compact Star	Masses M(M⊙)
J1823-3021G	2.65
J1518+4904	2.72
J1748-2446an	2.97

The recently discovered pulsar PSR J1823 3021G is known to be part of a binary system and has the potential of being one of the most massive known pulsars [43]. The same is noted with the binary pulsar PSR J1748-2446an which is a massive system that exceeds 2MΘ [44].

Conclusion

In this research we developed some simple relativistic charged stellar models obtained by solving Einstein-Maxwell field equations for a static spherically symmetric locally anisotropic fluid distribution. By choice of metric potential and the electric charge distribution together with the linear equation of state we have studied the behavior of fluid distribution. An analytical stellar model with such physical features could play a significant role in the description of internal structure of electrically charged strange stars. The newly obtained models match smoothly with the Schwarzschild exterior metric across the boundary r=R because matter variables and the gravitational potentials of this research are consistent with the physical analysis of these stars.

Physical features associated with the matter, radial pressure, density, anisotropy, charge density and the plots generated suggest that the proposed models can be compared with the pulsars PSR J1823-3021G, PSR J1748-2446an and PSR J1518+4904 and well behaved [43-44].

References

1. Kuhfitting PK (2011) Some remarks on exact wormhole solutions. Adv Stud Theor Phys 5: 365-367.
2. Bicak J (2006) Einstein equations: exact solutions. Encyclopedia of Mathematical Physics 2: 165-173.
3. Malaver M (2013) Black Holes, Wormholes and Dark Energy Stars in General Relativity. Lambert Academic Publishing, Berlin. ISBN: 978-3-659-34784-9.
4. Komathiraj K, Maharaj SD (2008) Classes of exact Einstein-Maxwell solutions. Gen Rel Grav 39: 2079-2093.
5. Sharma R, Mukherjee S, Maharaj SD (2001) General solution for a class of static charged stars. Gen Rel Grav 33: 999-1110.
6. Bowers RL, Liang EPT (1974) Anisotropic Spheres in General Relativity. Astrophys J 188: 657.
7. Malaver M, Iyer R (2022) Analytical Model of Compact Star with a New Version of Modified Chaplygin Equation of State. Applied Physics 5: 18-36.
8. Malaver M, Iyer R (2023) Charged Stellar Model with Generalized Chaplygin Equation of State Consistent with Observational Data. Universal Journal of Physics Research 2: 43-59.
9. Esculpi M, Malaver M, Aloma E (2007) A Comparative Analysis of the Adiabatic Stability of Anisotropic Spherically Symmetric solutions in General Relativity. Gen Relat Grav 39: 633-652.
10. Cosenza M, Herrera L, Esculpi M, Witten L (1982) Evolution of radiating anisotropic spheres in general relativity. Phys Rev D 25: 2527-2535.
11. Herrera L (1992) Cracking of self-gravitating compact objects. Phys Lett A 165: 206-210.
12. Herrera L, Nuñez L (1989) Modeling 'hydrodynamic phase transitions' in a radiating spherically symmetric distribution of matter. The Astrophysical Journal 339: 339-353.
13. Herrera L, Ruggeri GJ, Witten L (1979) Adiabatic Contraction of Anisotropic Spheres in General Relativity. The Astrophysical Journal 234: 1094-1099.
14. Herrera L, Jimenez L, Leal L, Ponce de Leon J, Esculpi M, et al. (1984) Anisotropic fluids and conformal motions in general relativity. J Math Phys 25: 3274.
15. Malaver M (2014) Quark Star Model with Charge Distributions. Open Science Journal of Modern Physics 1: 6-11.
16. Cosenza M, Herrera L, Esculpi M, Witten L (1981) Some models of anisotropic spheres in general relativity. J Math Phys 22: 118.
17. Gokhroo MK, Mehra AL (1994) Anisotropic spheres with variable energy density in general relativity. Gen Relat Grav 26: 75-84.
18. Sokolov AI (1980) Phase transitions in superfluid neutron liquid. Sov Phys JETP 52: 575.
19. Usov VV (2004) Electric fields at the quark surface of strange stars in the color-flavor locked phase. Phys Rev D 70: 067301.
20. Komathiraj K, Maharaj SD (2007) Analytical models for quark stars. Int J Mod Phys D 16: 1803-1811.
21. Malaver M (2016) Analytical models for compact stars with a linear equation of state. World Scientific News 50: 64-73.
22. Malaver M (2014) Some New Models for Strange Quark Stars with Isotropic Pressure. AASCIT Communications 1: 48-51.
23. Thirukkanesh S, Maharaj SD (2008) Charged anisotropic matter with linear equation of state, Class. Quantum Gravity 25: 235001.
24. Maharaj SD, Sunzu JM, Ray S (2014) Some simple models for quark stars. Eur Phys J Plus 129: 3.
25. Thirukkanesh S, Ragel FC (2013) A class of exact strange quark star model. PRAMANA- Journal of physics 81: 275-286.
26. Sunzu JM, Maharaj SD, Ray S (2014) Charged Anisotropic Models for Quark Stars. Astrophysics Space Sci 354: 517-524.
27. Feroze T, Siddiqui A (2011) Charged anisotropic matter with quadratic equation of state. Gen Rel Grav 43: 1025-1035.
28. Feroze T, Siddiqui A (2014) Some exact solutions of the Einstein-Maxwell equations with a quadratic equation of state. Journal of the Korean Physical Society 65: 944-947.
29. Malaver M (2014) Strange Quark Star Model with Quadratic Equation of State. Frontiers of Mathematics and Its Applications 1: 9-15.
30. Malaver M (2015) Relativistic Modeling of Quark Stars with Tolman IV Type Potential. International Journal of Modern Physics and Application 2: 1-6.
31. Takisa PM, Maharaj SD (2013) Some charged polytropic models. Gen Rel Grav 45: 1951-1969.
32. Thirukkanesh S, Ragel FC (2012) Exact anisotropic sphere with polytropic equation of state. PRAMANA-Journal of physics 78: 687-696.
33. Malaver M (2013) Analytical model for charged polytropic stars with Van der Waals Modified Equation of State. American Journal of Astronomy and Astrophysics 1: 41-46.
34. Malaver M (2013) Regular model for a quark star with Van der Waals modified equation of state. World Applied Programming 3: 309-313.
35. Thirukkanesh S, Ragel FC (2014) Strange star model with Tolmann IV type potential. Astrophysics and Space Science 352: 743-749.
36. Mak MK, Harko T (2004) Quark stars admitting a one-parameter group of conformal motions. Int J Mod Phys 13: 149-156.
37. Malaver M, Iyer R (2024) Modelling of Charged Dark Energy Stars in a Tolman IV Spacetime. Open Access Journal of Astronomy 2: 1-12.
38. Buchdahl HA (1959) General relativistic fluid spheres. Phys Rev 116: 1027.
39. Durgapal MC, Bannerji R (1983) New analytical stellar model in general relativity. Phys Rev 27: 328-331.
40. Lighuda AS, Maharaj SD, Sunzu JM, Mureithi EW (2021) A model of a three-layered relativistic star. Astrophys Space Sci 366: 76.
41. Bibi R, Feroze T, Siddiqui A (2016) Solution of the Einstein-Maxwell Equations with Anisotropic Negative Pressure as a Potential Model of a Dark Energy Star. Canadian Journal of

Physics 94: 758-762.
42. Yi-Zhong Fan, Ming-Zhe Han, Jin-Liang Jiang, Dong-Sheng Shao, Shao-Peng Tang (2024) Maximum gravitational mass MTOV=2.25+0.08−0.07M⊙ inferred at about 3% precision with multimessenger data of neutron stars. Phys Rev 109: 043052.
43. Ridolfi A, Gautam T, Freire PCC, Ransom SM, Buchner SJ, et al. (2021) Eight new millisecond pulsars from the first MeerKAT globular cluster census. MNRAS 504: 1407.
44. Janssen GH, Stappers BW, Kramer M, Nice DJ, Jessner A, et al. (2008) Multi-telescope timing of PSR J1518+4904. A&A 490: 753.